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BIOLOGICAL ACTIVITIES IN EDMONTON SOIL AS INFLUENCED BY CROP SEQUENCES

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V. Ignatieff

INTRODUCTION

Up to the middle of the last century plant nutrition and its relation to the soil and atmosphere was considered only from the chemical and physical points of view. However, in studying the soil as a medium for crop production we now have to consider the biological as well as the chemical and physical processes taking place in the soil and its solution. The underground portions of the living and dead plants are also important in this connection.

All of these factors, biological, chemical and physical, are closely interrelated and it is the purpose of this investigation to find out as much as possible about the effect of certain crops on the soil, and try to explain the peculiar influence that some crops have on other succeeding crops.

Briefly the work consisted of determining the moisture and nitrate concentration, and the number of micro-organisms in the soil throughout the growing season. Also since phosphorus plays an important part in the nutrition of plants and microorganisms, samples from the different plots

were analyzed for water soluble phosphorus, i.e., the most available form of phosphorus. In addition the nitrogen content of the plots was determined, because it was thought that cropping and cultural practices might affect the quantity of this element in the soil.

HISTORICAL

In this paper only a few of the earlier important researches will be mentioned in as much as a complete list of such references is to be found in Russell's text, Soil Conditions and Plant Growth#.

The primary importance of nitrates in plant nutrition was recognized as early as 1650 by Glauber, but what part these compounds played in building up of vegetable matter was not understood. Theodore de Saussure in 1804 realized that nitrogen was an essential element to the plant and that it was obtained from the soil. Boussingault in 1834 suggested that the leguminoseae were the only plants which were able to utilize the gaseous nitrogen from the air, but Liebig in 1840 was of the opinion that at least some crops other than leguminoseae could fix the free atmospheric nitrogen.

Soil Conditions and Plant Growth, by E. John Russell. Longmans, 1932.

This idea of Liebig was proved to be erroneous by the investigations carried out by Pugh at Rothamsted. Pugh's experiments were carried out under such strict conditions that even the leguminous plants were shown to be unable to grow without addition of combined forms of nitrogen. This was due to the fact that the methods employed prevented any of the plants being inoculated with the symbiotic bacteria.

It was Voelker, Ville, Berthelot, Hellriegel and Wilfarth who proved conclusively that the leguminous crops are the only ones able to utilize atmospheric nitrogen.

The prevalent opinion of the present day seems to be that plants, other than the leguminoseae,utilize nitrates as their chief source of nitrogen, although they can also make use of ammonium compounds by means of their root system.

Having attempted to explain by this short historical outline why at the present day so much time and space is alloted to the study of nitrates in all soil fertility investigations, we shall try to show what relationship microbiology has to this type of work.

Pasteur, about the middle of the last century, suggested that soil nitrates have a biological origin. Schloessing, Muntz, Warington and Winogradsky by a series of experiments carried out later on showed that the bacteria were responsible for the formation of nitrates in the soil.

In 1884 Wollny pointed out that decomposition of organic substance in the soil was retarded by the application

of antiseptics. From that time on many investigators have demonstrated that the decomposition of plant residues is carried out by soil organisms, and of late years researchers such as Waksman, Skinner and Heukelekian (14,49,62), have come to the conclusion that a very large part of this work is performed by soil fungi. Now a supply of available nitrogen in the form of nitrate or ammonium salts is required by these organisms, and thus they enter into direct competition with the growing plant for one of the most important elements.

In the last twenty or thirty years a tremendous amount of work has been done on the reciprocal effects of crops, microorganisms and concentration of nitrates in the soil. It is beyond the scope of this report to review all the literature published on this subject. However, the results of the most recent and significant investigations will be briefly stated.

King and Whitson, Stewart and Greaves and Russell (25,47,56) found that the period of loss of nitrate content in the soil during the summer months coincided with the period of rapid growth of crops. Investigators such as King and Whitson, Ponget and Luirand, Jensen, Russell, Whiting and Schoonover (25,46,47,66) showed that the most active period of production and accumulation of nitrates was the late spring and early summer, and that there was an increase in nitrate content of the soil in the early autumn, following a period of low content in the late summer. Vogel, from his work, concluded that treatment of the soil had less effect upon nitrification than

the time of the year, whereas Lemmermann and Wickers (29) stated that there is not sufficient evidence to show a direct periodic influence of the time of year on life activities of the organisms, and they believe that the physical factors affect the process. There seems to be no doubt that nitrification is affected very materially by variation in moisture content of the soil.

Lyon, Bizzell and Wilson, McBeth and Smith, Greaves, Stewart and Hirst (11,31,38,64) support the view that greater amounts of nitrates are produced in the soil after crops of clover and alfalfa, or when these crops have been plowed under, than after cereals and grasses. This opinion is supported by most of the experimental evidence of the present day, although a few workers such as King and Whitson and Brown have obtained results which do not entirely agree with this finding.

The study of decomposition of plant residues is still in its infancy, but much work has been done in this field by Heukelekian, Skinner, Waksman, Collison, Conn and Hill (5,14,15, 51,62). Their work has shown that aerobic and anaerobic bacteria and fungi are capable of decomposing organic matter, and that these organisms enter into competition with the living plants for the supply of available nitrogen. Starkey (54,55), who has investigated the influence of higher plants on microorganisms, has concluded that the former have a stimulating effect on the latter.

There are many other relationships that exist between the growing plants, their residues and the soil organisms, but

these will be discussed with the data of the experiments reported.

OUTLINE OF THE INVESTIGATION

The investigation was commenced in June 1927, when a block 205 x 615 links was seeded down. On the north side a strip 15 links wide, which was not used for experimental purposes, was filled out with the same crops as an adjacent plot. The remainder of the area was divided into three equal sub-blocks, I, II, III, with sixteen plots in each arranged according to the Latin system, with paths between them. Strips two feet wide around each plot were discarded, thus leaving a net area for experimental purposes of 46 x 46 links.

Plan of the Plots

N ←

	Sub-block I				Sub-block II				Sub-block III			
R	1 T	2 A	3 B	4 WR	1 A	2 B	3 T	4 WR	1 T	2 A	3 B	4 WR
E E	5 WR	6 B	7 T	8 A	5 WR	6 A	7 B	8 T	5 A	6 B	7 WR	8 T
D F	9 B	10 WR	11 A	12 T	9 B	10 T	11 WR	12 A	9 WR	10 T	11 A	12 B
B	13 A	14 T	15 WR	16 B	13 T	14 WR	15 A	16 B	13 B	14 WR	15 T	16 A

Broken 1928 Broken 1930 To be broken 1932

The following crops were seeded on each sub-block in quadruplicates:

	Rate of Seeding
Timothy	8 lbs. per acre
Western Rye grass	10 " " "
Brome grass	19 " " "
Alfalfa	10 " " " (inoculated)

The seeding was carried out east and west, 50 rows 1 link apart being alloted to each plot.

Breaking

The sub-block I was plowed up immediately after cutting hay in beginning of July 1928, the sub-block II was broken in middle of July 1930.

In plowing the furrow slices were turned over flat and packed at once. The seed bed for wheat was prepared the spring following. Wheat was grown continuously on all the plots after breaking.

Soil Sampling

3-4	borings	for	surface	samples	to	the	depth	of	6 2/3"	level A
2	"	"	subsurface	"	"	"	"	"	20"	" B
1-2	"	"	subsoil	"	"	"	"	"	40"	" C

were made per plot.

During the first season samples were taken just before seeding and again at monthly intervals until the autumn. After

the first year samples were taken at monthly intervals throughout the summer, beginning about the middle of May and finishing at the end of September. It was attempted to have one of the samplings coincide with the cutting of hay. Nitrate and moisture analyses were carried out on these samples.

Nitrogen content was determined on samples taken in May each year, and during 1931 water soluble phosphates were determined on samples taken throughout the season.

For obtaining the bacterial and fungi counts samples to a depth of 6 2/3 inches were taken at fortnightly intervals throughout the summer.

METHODS OF ANALYSIS

For moisture determination 300 grams of moist soil were dried in the oven at a temperature of 60-70° C. The percentage moisture was calculated on oven-dry soil basis.

The soil thus treated was then ground and stored in sealers for use in all the other analyses.

The nitrate determination was carried out according to the phenol-disulphonic method as modified by H. J. Harper (13).

The Deniges method as modified by Parker (42) was used in analysis of water soluble phosphates.

The total nitrogen was determined by the Gunning-Hibbard method (12).

A few words regarding the procedures employed will not be out of place. Both the phenol-disulphonic and phospho molybdic methods are useful because they are rapid and are sufficiently accurate.

Phenol-Disulphonic Method

The yellow colour developed remains for a considerable number of hours, thus permitting many samples to be dealt with at the same time. The main drawbacks of this method are:

1. It is difficult to compare the intensity of the yellow colour.

2. The readings are to a certain extent subject to variation in different lights.

3. The personal element perhaps is of greater importance in this method than is desirable.

The Deniges or Phospho Molybdic Method

By this procedure one can measure minute quantities of phosphate with accuracy. The weakness of the method lies in the fact that it calls for a great precision in measuring out the reagents, which causes delay, whereas rapidity is essential in carrying out the determination, because the blue colour developed by reduction of the complex phospho molybdic acid fades rapidly on exposure to air.

Gunning - Hibbard Method for Total Nitrogen

The only point of interest to be mentioned in this method is that it does not account for nitrogen in the form of nitrates.

Method for Determination of Numbers of Microorganisms

The cultural plate method was employed for determining the bacterial and fungal numbers. As stated previously soil samples to a depth of six inches were taken at fortnightly intervals throughout the growing season, commencing about the middle of May and ending about the middle of September. Realizing that the number of microorganisms have a daily fluctuation each sampling was done at approximately the same time of the day.

The samples were brought into the laboratory in glass sealers and were plated out with the least possible delay.

The medium used for total counts was the Sodium Caseinate or Nutrose Agar of the following composition:

Agar		12.5 grams
Sodium caseinate or Nutrose		2.0 "
Glucose		1.0 "
Dipotassium phosphate	K_2HPO_4	.2 "
Magnesium sulphate	$MgSO_47H_2O$	.2 "
Ferrous sulphate	$FeSO_4.7H_2O$	trace
Tap water		1000 cc.

The advantage of this medium is that it is easily prepared, sets firm in a very short time and gives a reaction of approximately pH 6.8 without any special adjustment.

The medium used for fungi counts has the reaction pH 3.8-4, and is made up as follows:

Agar	25 grams
Monopotassium phosphate (KH_2PO_4)	1 "
Magnesium sulphate ($MgHSO_4 7H_2O$)	.5 "
Peptone	5 "
Glucose	10 "
Water	1000 cc.

1 cc. of $\frac{N}{2}$ H_2SO_4 per 100 cc. of medium.

The use of this medium is recommended by Waksman (61). Unfortunately, being a peptone agar, it stimulated the quick growth of the proteotytic fungus, Mucor, which in certain cases prevented the appearance of slower developing fungi such as Penicillium.

The chief disadvantages of this method are:

1. The bacterial and fungal counts obtained from different dilutions show no mathematical correlation.

2. Only the heterotrophic bacteria and not even all of this class are the ones that develop on this medium.

3. In the case of fungi it is not known what is actually represented by the colonies found on the plates, whether they developed from pieces of broken up mycelian, or from dormant spores. However, with all its weaknesses this is the most practical method in use at the present time for determining the numbers of microorganisms in the soil.

EXPERIMENTAL RESULTS

The results obtained from this investigation, carried out during a period of five years from 1927-1931, will be discussed under four headings.

1. Nitrate nitrogen and moisture investigation.
2. Water soluble phosphorus.
3. Total nitrogen.
4. Microorganisms.

The writer himself is responsible only for one year's work, the analyses for the previous years having been carried out by other members of the Soils Department of the University of Alberta.

Nitrate Nitrogen and Moisture Investigation

The results obtained from the investigation of the nitrate concentration of the soil under the different crops during the five year period from 1927-1931 are recorded in Tables I to VI and Graphs I to III. The detailed analytical data for 1931 are given in Table I, and have been obtained from the composite samples of soil consisting of composite samples taken from four similar plots from each sub-block. The concentration of nitrate nitrogen of the different plots at the three depths is expressed as milligrams per hundred grams of soil. Tables II to VI show the amount of nitrate

nitrogen in pounds per acre present in the soil to a depth of 40 inches at the different sampling dates during the period of five years.

As a rule the greatest amount of nitrate was found in the top six inches of the soil with a gradual decrease downwards, but this is not always the case. It is fairly certain that the nitrification proceeds at the greatest rate in the upper layer of soil, but there may be two causes responsible for the occasional greater concentration of nitrates at the lower depth, the leaching downward of easily soluble salts and the utilization of nitrate near the surface by plants or microorganisms.

When inspecting Graphs I, II and III and Table II one of the chief points to be noticed is that as soon as the experimental land was seeded down to perennial crops in 1927 the concentration of nitrates in the soil was immediately decreased and remained low under the sod. This depressing effect of hay crops is clearly seen if one inspects the figures in the "seasonal average" column of Tables II to VI.

The figures in the "seasonal average" column for the year 1927 (Table II) roughly range about 150-200 pounds per acre for all plots. In 1928 (Table III) the second year of growth of the perennial crops, the figures show only from one half to one third that amount. In the middle of that summer block I was plowed up and this resulted in a rise in the amount of nitrates in the soil of that sub-block from an average of 65 pounds per acre in the month of August, to 132 pounds in

the month of September, whereas the average content of the plots of the other blocks remained about 60 pounds.

Tables IV and V show that the amount of nitrate in the soil in all the plots of sub-block I growing crops of wheat, was considerably greater than in plots seeded down to hay crops.

In 1930 sub-block II was plowed up in middle of July. When we inspect Table V we notice an immediate rise in nitrate concentration of all the plots in sub-block II from a trace of nitrate during the month of July to about 30-80 pounds of nitrate nitrogen in the month of August.

The wet season of 1931 was favourable for the process of nitrification and tended to even up the differences in nitrate concentration under the different crops, yet the depressing effect on soil nitrates of perennials in sub-block III is seen clearly in Table VI. Western rye grass proved to be an exception in this case, but it must be stated that there was a very poor stand of this grass throughout the 1931 season, probably due to winter killing. The absorption of nitrates by this crop in 1931 would therefore be greatly reduced.

Nitrate determinations on fallow land were carried out during three seasons 1929 to 1931. It will be seen from the "seasonal average" column of Tables VI, V and IV that the nitrate content of this land is greater than that of any other plot in 1931, whereas in 1930 and 1929, it is second only to the broken up alfalfa plots of sub-block I. Actually the fallow land was highest in nitrates in the latter half of all

three seasons (18).

Now if the soil under the different crops of the three sub-blocks are considered one finds that the broken up alfalfa plots supporting crops of wheat are at the top of the list. If the "order of averages" column of Tables IV, V and VI are studied, this point will become very apparent. A number of investigators such as Brown, Greaves, Lyon, Bizzell, Wilson, Martin, McBeth have shown that alfalfa land when broken up yields great amounts of nitrates (3,11,30,31,32,36,38).

The wheat plots after western rye and timothy are next on the list. One point of interest is that the decomposition of timothy sod does not seem to be detrimental to nitrate production, yet many farmers report that timothy has an adverse effect on the wheat crop that follows it. It is hard to explain satisfactorily this phenomenon except by suggesting that toxins are produced by timothy. These plant toxins may be formed in two ways. They may be excreted by living plants as suggested by Whitney, Cameron and Pickering, or they can be formed during the decomposition of the dead vegetable matter (8, 64). At the present stage of investigation one should avoid being too dogmatic on this point, but the second viewpoint seems to be a more reasonable one, especially as the possible toxins excreted by living plants have not as yet been isolated.

Plowed up brome sod is relatively low in nitrate concentration, as will be seen by referring to the last two columns of Tables IV to VI. This may be due to the utilization

Figure I

Figure II

These figures show the difference in wheat crop after brome on the left and after alfalfa on the right. Note the denser foliage and heavier stand of wheat after alfalfa.

of available nitrogen by the fungi engaged in the decomposition of the organic carbonaceous material. This opinion is substantiated by the fungi counts (Table VIII) carried out during the summer of 1931. Collison and Conn, Heuhelekian, Waksman and Skinner, have shown that cellulose is decomposed in the soil to a large extent by fungi, which require a source of available nitrogen (5,13,14,62). This low nitrate content of the soil after brome may be partly responsible for the poor wheat crops as seen in Figures I and II.

It has already been pointed out that the soil of the plots under the growing grasses and alfalfa was low in nitrate content, but that the amount of nitrates greatly increased in the soil when the perennials were plowed up. The point that requires stressing is that the nitrate concentration of broken up sod remains relatively high, even when the plots are cropped to wheat, as seen from Tables IV to VI and Graphs I to III.

There is not much difference found in the amount of nitrates under alfalfa and the grasses, yet it may be stated that as a rule in this investigation nitrate concentration under alfalfa was found to be a little greater than under grasses. Brome again has to be placed last on the list, whereas timothy and western rye grass are in the intermediate position. Albrecht's (1) work substantiated the view that there is never any great concentration of nitrates under grasses, such as timothy but Jones (21) considered that the low nitrate content of the soil under timothy is due to the

utilization of the soil nitrates by this crop, and not to any special depressing effect of the crop on the process of nitrification.

In concluding this discussion on the results obtained from nitrate determination a few words should be said about the relationship between the time of the year and the amount of nitrate in the soil. The fallow plots, for which the nitrate determinations have been carried out for the last three summers, show an upward trend, usually, in their nitrate curve during the progress of the season, as seen in the Graph I (10,19,29,46,47,66,69). But nothing definite can be said in this connection with regard to the other plots, nor can one notice any definite correlation between the fluctuations of moisture in the soil and nitrate concentration. The lack of correlation between the nitrates and the moisture figures may be explained by the fact that the moisture determinations were made once a month on the samples analyzed for nitrates. Now it may have happened in certain cases that the samplings were immediately preceded by rain; the soil in that case would be wet, and yet not enough time would have elapsed to allow the change in moisture content of the soil to have its full effect on the activities of the microorganisms. Furthermore, it should be kept in mind that in all cases except the summerfallow, crops were growing on plots and consequently utilized both moisture and nitrates. On comparing the data of Tables V and VI of the dry season of 1930 and the wet season of 1931 one notices that the nitrate concentra-

tion of the soil was higher in 1931 than in 1930, tending to show that up to a certain point moisture stimulates nitrification.

The moisture content of the surface soil of the different plots growing crops do not show any great differences. This statement is true not only with regard to the surface soil, but is equally correct with regard to the moisture content of the soil down to the depth of 40 inches. The only significant exception occurs in the case of the fallow which is somewhat higher. This plot is always the highest in moisture content. Duley, however, found that old stands of alfalfa reduced to an appreciable extent the soil moisture at the lower depths (9).

We can see from our experiments that it is not an excessive utilization of moisture by brome that is responsible for the poor wheat crops following this grass. This would throw some doubt on the popular idea among farmers at the present time that brome causes poor wheat growth by drying out the land.

Table I. Nitrate nitrogen and moisture in soil from sub-blocks I, II and III (1931)

May 13th.

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A	I	Third crop	18.1	2.69
B	"	wheat after	13.8	1.14
C	"	timothy	10.5	.67
A	I	Third crop	19.8	3.70
B	"	wheat after	11.9	1.85
C	"	alfalfa	14.9	.58
A	I	Third crop	19.8	3.17
B	"	wheat after	12.2	.77
C	"	brome	16.5	Trace
A	I	Third crop	20.0	2.72
B	"	wheat after	11.2	1.61
C	"	western rye	14.4	.54
A	II	First crop	17.9	4.93
B	"	wheat after	13.3	.99
C	"	alfalfa	12.1	Trace
A	II	First crop	21.5	2.48
B	"	wheat after	13.0	.42
C	"	brome	10.2	S. Trace
A	II	First crop	20.9	4.82
B	"	wheat after	12.0	.66
C	"	timothy	10.0	Trace
A	II	First crop	16.9	5.97
B	"	wheat after	11.8	.50
C	"	western rye	10.0	Trace
A	III	Timothy	12.4	.90
B	"	"	11.8	.35
C	"	"	14.3	1.41
A	III	Alfalfa	13.1	1.69
B	"	"	11.6	.45
C	"	"	13.7	Trace
A	III	Brome	13.4	.74
B	"	"	10.7	Trace
C	"	"	9.5	S. Trace

Table I (Continued)

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A	III	Western rye	19.0	2.22
B	"	"	10.6	.33
C	"	"	13.4	Trace
A		Fallow	18.0	5.97
B		"	14.4	2.44
C		"	14.4	.42
		June 25th.		
A	I	Third crop	28.1	1.10
B	"	wheat after	16.0	1.43
C	"	timothy	18.1	.48
A	I	Third crop	30.4	1.30
B	"	wheat after	14.9	1.69
C	"	alfalfa	16.7	.38
A	I	Third crop	27.1	1.86
B	"	wheat after	15.4	.87
C	"	brome	16.5	.33
A	I	Third crop	28.4	1.27
B	"	wheat after	15.2	1.49
C	"	western rye	19.4	.40
A	II	First crop	30.5	2.42
B	"	wheat after	18.8	1.28
C	"	alfalfa	14.2	S. Trace
A	II	First crop	31.6	1.31
B	"	wheat after	18.3	S. Trace
C	"	brome	14.2	V.S. Trace
A	II	First crop	30.6	.85
B	"	wheat after	19.8	.91
C	"	timothy	17.4	.68
A	II	First crop	33.2	1.52
B	"	wheat after	17.9	.81
C	"	western rye	12.5	V.S. Trace

Table I (Continued)

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A	III	Timothy	33.6	.70
B	"	"	19.3	Trace
C	"	"	18.7	.34
A	III	Alfalfa	31.5	.73
B	"	"	17.5	S. Trace
C	"	"	14.9	V.S. Trace
A	III	Brome	27.9	.89
B	"	"	17.7	S. Trace
C	"	"	14.1	V.S. Trace
A	III	Western rye	35.3	1.25
B	"	"	19.7	1.23
C	"	"	15.2	.39
A		Fallow	28.9	3.84
B		"	19.7	3.96
C		"	11.4	.79
		July 24th.		
A	I	Third crop	24.7	.71
B	"	wheat after	18.3	.55
C	"	timothy	15.7	.42
A	I	Third crop	27.3	.89
B	"	wheat after	17.6	.76
C	"	alfalfa	17.1	.42
A	I	Third crop	24.6	.69
B	"	wheat after	18.2	.33
C	"	brome	17.2	.19
A	I	Third crop	25.5	.88
B	"	wheat after	18.2	.48
C	"	western rye	11.2	.31

Table I (Continued)

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A	II	First crop	25.6	.88
B	"	wheat after	21.0	.70
C	"	alfalfa	13.5	V.F. Trace
A	II	First crop	27.5	.75
B	"	wheat after	23.9	.20
C	"	brome	14.5	V.F. Trace
A	II	First crop	26.0	.79
B	"	wheat after	20.7	.31
C	"	timothy	14.1	.37
A	II	First crop	25.8	.89
B	"	wheat after	21.1	.40
C	"	western rye	13.3	V.F. Trace
A	III	Timothy	27.0	.77
B	"	"	26.5	.37
C	"	"	20.8	.27
A	III	Alfalfa	25.0	.91
B	"	"	21.9	.40
C	"	"	16.9	V.F. Trace
A	III	Brome	27.9	.75
B	"	"	24.7	.33
C	"	"	14.6	V.F. Trace
A	III	Western rye	29.5	1.00
B	"	"	27.4	.94
C	"	"	16.8	.17
A		Fallow	32.2	1.61
B		"	25.6	3.39
C		"	19.8	.78
		August 18th.		
A	I	Third crop	29.4	.43
B	"	wheat after	20.0	Trace
C	"	timothy	19.1	F.L. Trace

Table I (Continued)

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A	I	Third crop	28.2	.38
B	"	wheat after	18.9	Trace
C	"	alfalfa	16.8	F.L. Trace
A	I	Third crop	30.9	.36
B	"	wheat after	20.5	S. Trace
C	"	brome	16.5	V.S. Trace
A	I	Third crop	29.9	.42
B	"	wheat after	21.6	Trace
C	"	western rye	15.7	F.L. Trace
A	II	First crop	31.6	.42
B	"	wheat after	19.3	.57
C	"	alfalfa	14.0	V.F. Trace
A	II	First crop	33.3	.47
B	"	wheat after	23.7	S. Trace
C	"	brome	14.1	V.F. Trace
A	II	First crop	26.7	.49
B	"	wheat after	20.9	S. Trace
C	"	timothy	17.3	F.L. Trace
A	II	First crop	30.5	.49
B	"	wheat after	24.0	S. Trace
C	"	western rye	15.7	F. Trace
A	III	Timothy	35.7	.79
B	"	"	27.7	S. Trace
C	"	"	19.4	F. Trace
A	III	Alfalfa	35.6	1.06
B	"	"	27.5	S. Trace
C	"	"	17.1	V.F. Trace
A	III	Brome	33.9	.73
B	"	"	27.5	S. Trace
C	"	"	17.7	V.F. Trace
A	III	Western rye	35.6	1.15
B	"	"	27.2	.43
C	"	"	22.2	F. Trace

Table I (Continued)

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A		Fallow	32.7	2.08
B		"	23.9	2.22
C		"	22.4	2.44
		September 15th. (subsoil) 25th. (surface and subsurface)		
A	I	Third crop	23.7	.94
B	"	wheat after	15.1	Trace
C	"	timothy	17.9	.45
A	I	Third crop	27.2	.73
B	"	wheat after	15.5	.56
C	"	alfalfa	19.7	.45
A	I	Third crop	27.4	.86
B-	"	wheat after	18.0	Trace
C	"	brome	17.9	S. Trace
A	I	Third crop	30.1	.57
B	"	wheat after	16.1	.59
C	"	western rye	16.4	.47
A	II	First crop	25.2	.81
B	"	wheat after	16.4	.67
C	"	alfalfa	14.6	S. Trace
A	II	First crop	30.3	.77
B	"	wheat after	20.8	Trace
C	"	brome	16.5	S. Trace
A	II	First crop	26.3	.73
B	"	wheat after	17.8	Trace
C	"	timothy	16.5	.43
A	II	First crop	26.8	.98
B	"	wheat after	20.9	.52
C	"	western rye	15.2	.30

Table I (Continued)

Sample	Sub-block	Crop	Moisture %	Nitrate nitrogen mgm. per 100 grams soil
A	III	Timothy	27.7	.69
B	"	"	20.1	Trace
C	"	"	19.8	V.S. Trace
A	III	Alfalfa	20.5	.86
B	"	"	16.1	Trace
C	"	"	15.2	V.S. Trace
A	III	Brome	28.9	.86
B	"	"	21.6	Trace
C	"	"	17.2	V.S. Trace
A	III	Western rye	29.7	.86
B	"	"	23.7	.60
C	"	"	18.2	.34
A		Fallow	32.1	3.22
B		"	22.0	1.92
C		"	23.3	2.20

Table II. Nitrate nitrogen pounds per acre (1927)
(to depth of 40 inches)

Sub-block	Crop	June 15	July 15	August 13	Sept. 11	Seasonal average	Order of averages
I	Timothy	234.2	209.2	139.0	125.8	177.1	1
"	Alfalfa	228.2	193.6	171.0	106.6	174.8	2
"	Brome	180.2	198.2	117.6	102.8	149.7	4
"	Western rye	191.6	202.0	133.6	94.2	155.4	3
II	Alfalfa	235.0	227.8	212.0	150.4	206.3	1
"	Brome	234.4	201.2	175.8	127.0	184.6	3
"	Timothy	239.6	189.2	138.2	108.8	168.9	4
"	Western rye	290.2	202.6	168.2	142.2	200.8	2
III	Timothy	278.0	233.2	194.8	166.0	218.0	3
"	Alfalfa	274.4	266.4	243.6	164.8	237.3	1
"	Brome	321.0	231.0	184.2	128.8	216.2	4
"	Western rye	319.8	235.8	210.8	137.0	225.8	2

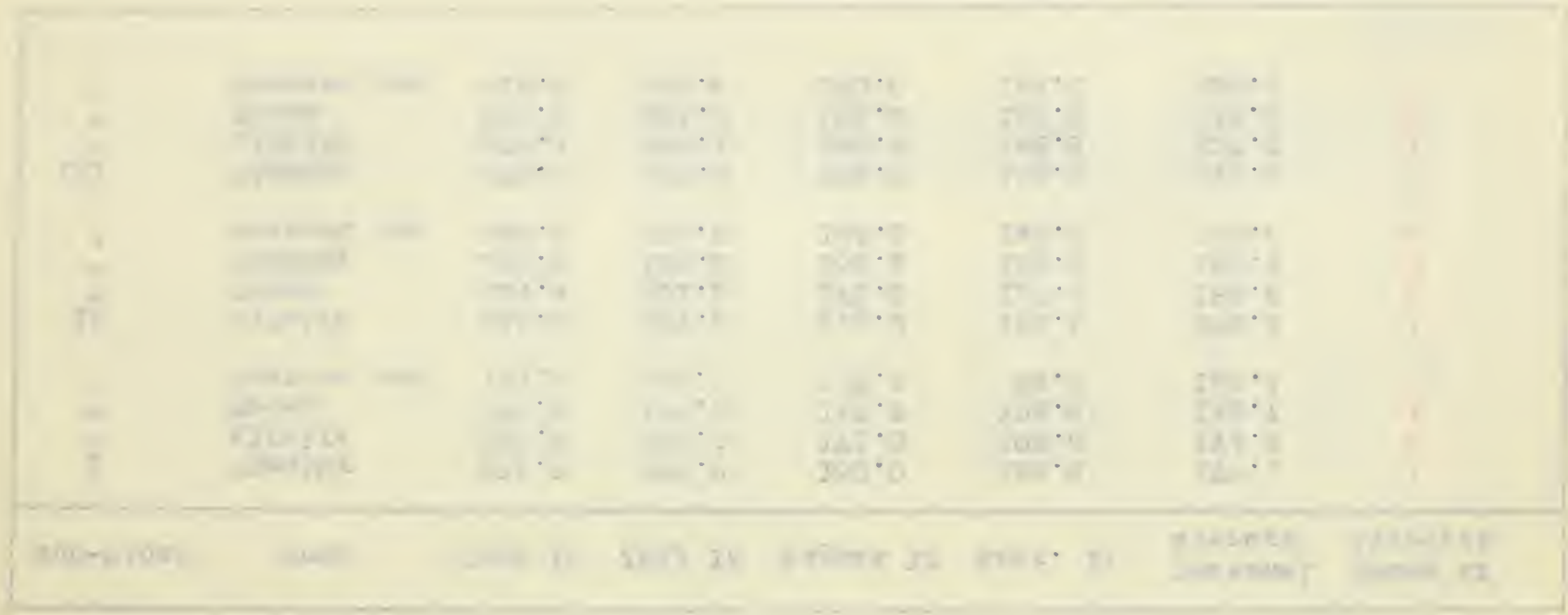


Table III. Nitrate nitrogen pounds per acre (1928)
(to depth of 40 inches)

Sub-block	Crop	May 17	June 15	July 10	August 16	Sept. 19	Seasonal average	Order of averages
I	Timothy	56.0	62.2	46.2	59.4	137.2	72.2	3
"	Alfalfa	47.0	44.4	41.0	82.8	160.4	75.1	2
"	Brome	45.8	32.6	----	35.6	102.2	54.1	4
"	Western rye	135.4	46.4	57.8	84.0	131.2	91.0	1
II	Alfalfa	133.0	92.2	64.6	52.4	57.4	79.9	2
"	Brome	77.2	58.8	----	40.0	52.4	57.1	4
"	Timothy	105.0	88.4	94.0	52.4	58.2	79.6	3
"	Western rye	112.6	100.4	66.8	67.6	55.2	80.5	1
III	Timothy	166.0	102.8	109.4	81.8	59.6	103.9	1
"	Alfalfa	131.6	57.8	86.6	45.0	60.6	76.3	3
"	Brome	85.0	41.4	-----	68.0	50.4	61.2	4
"	Western rye	101.2	79.0	101.4	86.2	62.6	86.1	2
"								

Table IV. Nitrate nitrogen pounds per acre (1929)
(to depth of 40 inches)

Sub-block	Crop	May 14	June 17	July 15	Aug.2,7	Sept.11	Seasonal average	Order of averages
I	Wheat# after timothy	138.0	133.0	57.4	96.0	127.2	110.3	3
"	" " alfalfa	122.8	197.8	82.6	112.2	120.2	127.1	1
"	" " brome	57.9	101.4	65.8	40.8	60.2	65.2	4
"	" " W. rye	131.2	113.8	93.4	102.6	163.6	118.9	2
II	Alfalfa	41.8	33.0	17.4	17.6	8.0	23.6	1
"	Brome	trace	trace	10.2	12.8	trace	4.6	2
"	Timothy	trace	trace	8.6	trace	trace	1.7	4
"	W. rye	trace	trace	12.2	7.4	trace	3.9	3
III	Timothy	trace	trace	30.2	trace	trace	6.0	2
"	Alfalfa	33.0	trace	28.0	13.8	7.4	16.4	1
"	Brome	trace	trace	trace	trace	trace	trace	4
"	W. rye	trace	trace	8.6	trace	trace	1.7	3
	Fallow	62.8	84.8	114.6	151.4	217.6	126.2	

First crop of wheat after breaking.

Table V. Nitrate nitrogen pounds per acre (1930)
(to depth of 40 inches)

Sub-block	Crop	May 12	June 16	July 14	Aug. 22	Sept. 19	Seasonal average	Order of averages
I	Wheat# after timothy	108.4	94.6	33.2	130.4	36.4	80.6	2
"	" " alfalfa	112.8	96.0	71.8	147.6	55.0	96.6	1
"	" " brome	78.4	128.4	36.4	95.6	23.2	72.4	4
"	" " W. rye	84.6	71.0	36.4	143.8	39.0	75.0	3
II	Alfalfa	15.2	34.4	trace	83.8	45.6	35.8	1
"	Brome	trace	trace	none	33.6	5.4	7.8	4
"	Timothy	trace	trace	none	81.6	14.2	19.1	2
"	W. rye	trace	trace	trace	53.4	22.2	15.1	3
III	Timothy	trace	41.4	trace	55.4	trace	19.4	1
"	Alfalfa	11.0	13.2	trace	23.6	trace	9.6	2
"	Brome	trace	trace	none	trace	trace	trace	4
"	W. rye	trace	trace	trace	35.0	trace	7.0	3
	Fallow	71.0	42.8	110.0	192.4	60.4	95.3	

Second crop of wheat after breaking.

Table VI. Nitrate nitrogen pounds per acre (1931)
(to depth of 40 inches)

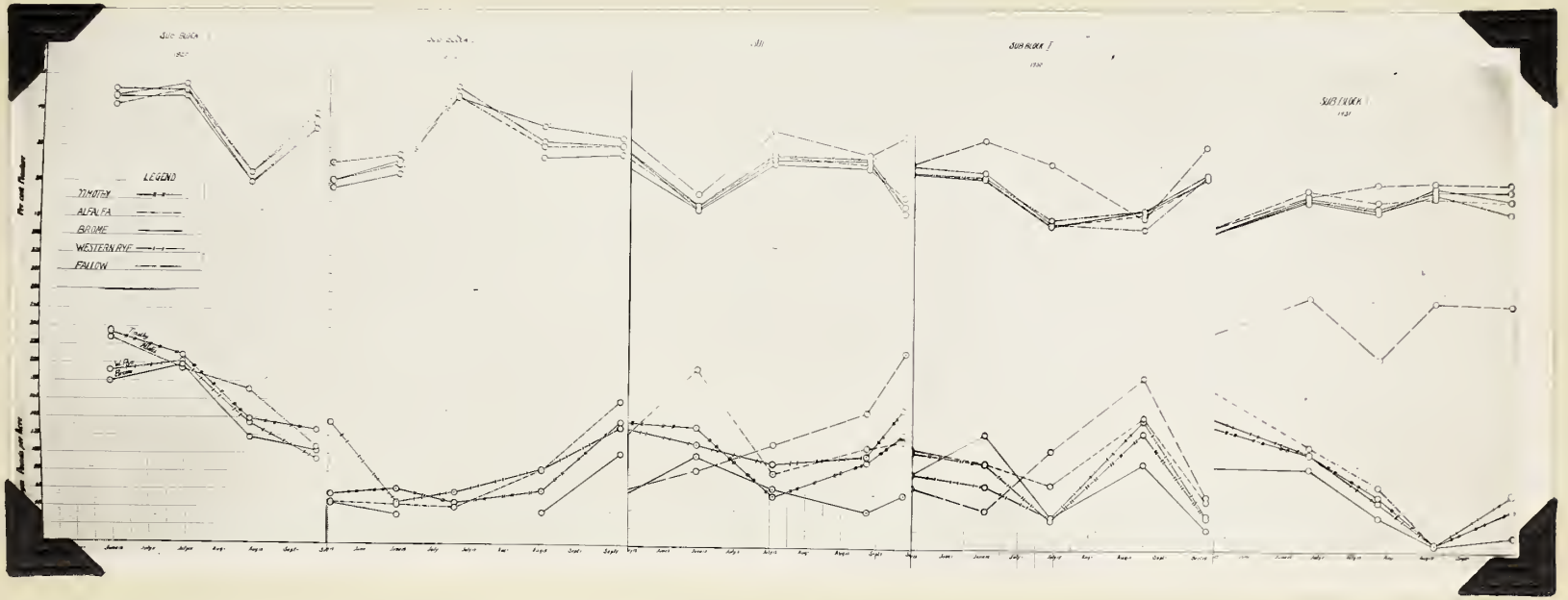
Sub-block	Crop	May 13	June 25	July 24	Aug.18	Feb.15,25	Seasonal average	Order of averages
I	Wheat# after timothy	139.6	108.0	61.4	8.6	45.8	72.6	3
"	" " alfalfa	182.8	116.4	73.4	7.6	64.0	88.8	1
"	" " brome	94.2	91.8	38.4	7.2	17.2	49.8	4
"	" " W. rye	151.2	109.0	55.4	8.4	63.2	77.4	2
II	Wheat## after alfalfa	138.2	99.6	45.6	31.2	43.0	71.5	1
"	" " brome	66.4	26.2	23.0	9.4	15.4	28.1	4
"	" " timothy	122.8	94.2	50.4	9.8	40.4	63.5	2
"	" " W. rye	139.4	62.8	33.8	9.8	58.4	60.8	3
III	Timothy	116.6	34.4	46.4	15.8	13.8	45.4	2
"	Alfalfa	51.8	14.6	34.2	21.2	17.2	27.8	3
"	Brome	14.8	17.8	28.2	14.6	17.2	18.5	4
"	W. rye	57.6	107.6	67.8	40.2	61.6	67.0	1
	Fallow	242.2	282.6	214.6	276.8	273.2	257.9	

Third crop of wheat after breaking.

First crop of wheat after breaking.

Graph I

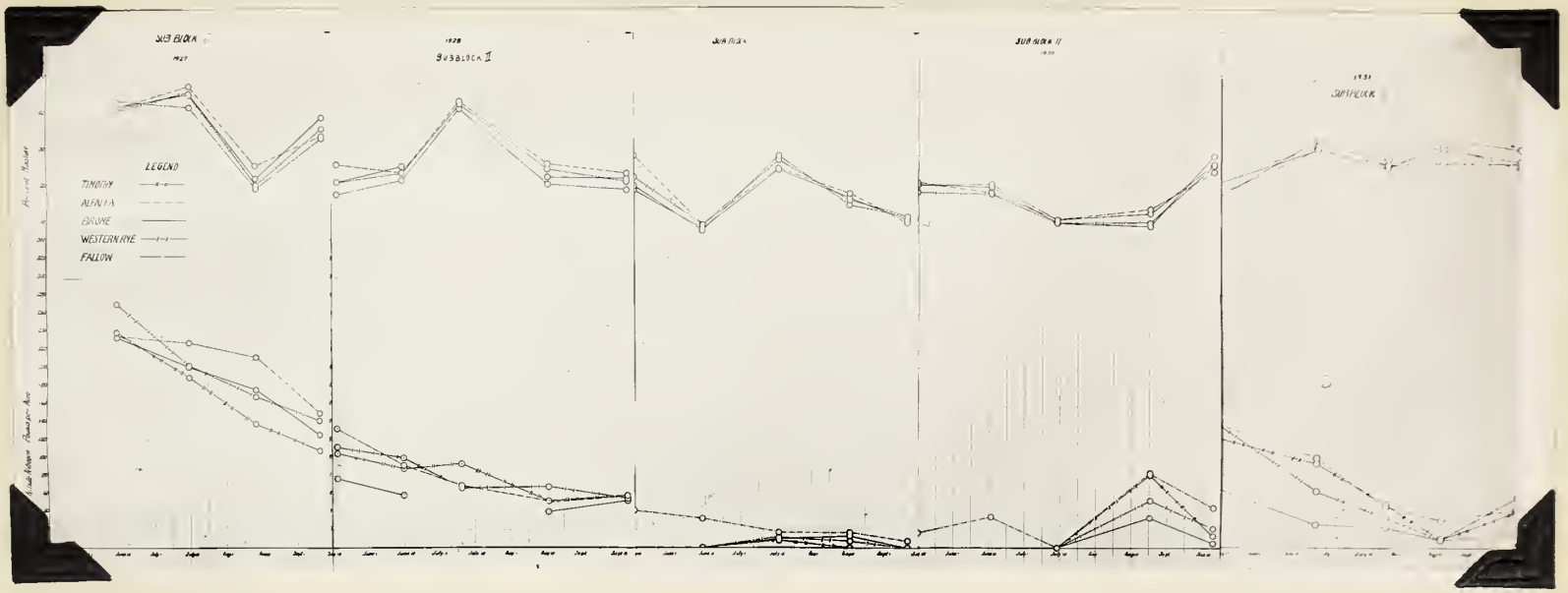
Graphical representation of the concentration of nitrates and moisture in sub-block I (1927-1931).



Nitrate nitrogen expressed as lbs. per acre in upper 40 inches of soil. The figures for moisture content represent only the upper 6 inches of soil. Note that the sub-block was plowed up in the middle of July 1928. Graph shows nitrates produced under wheat from 1929-1931.

Graph II

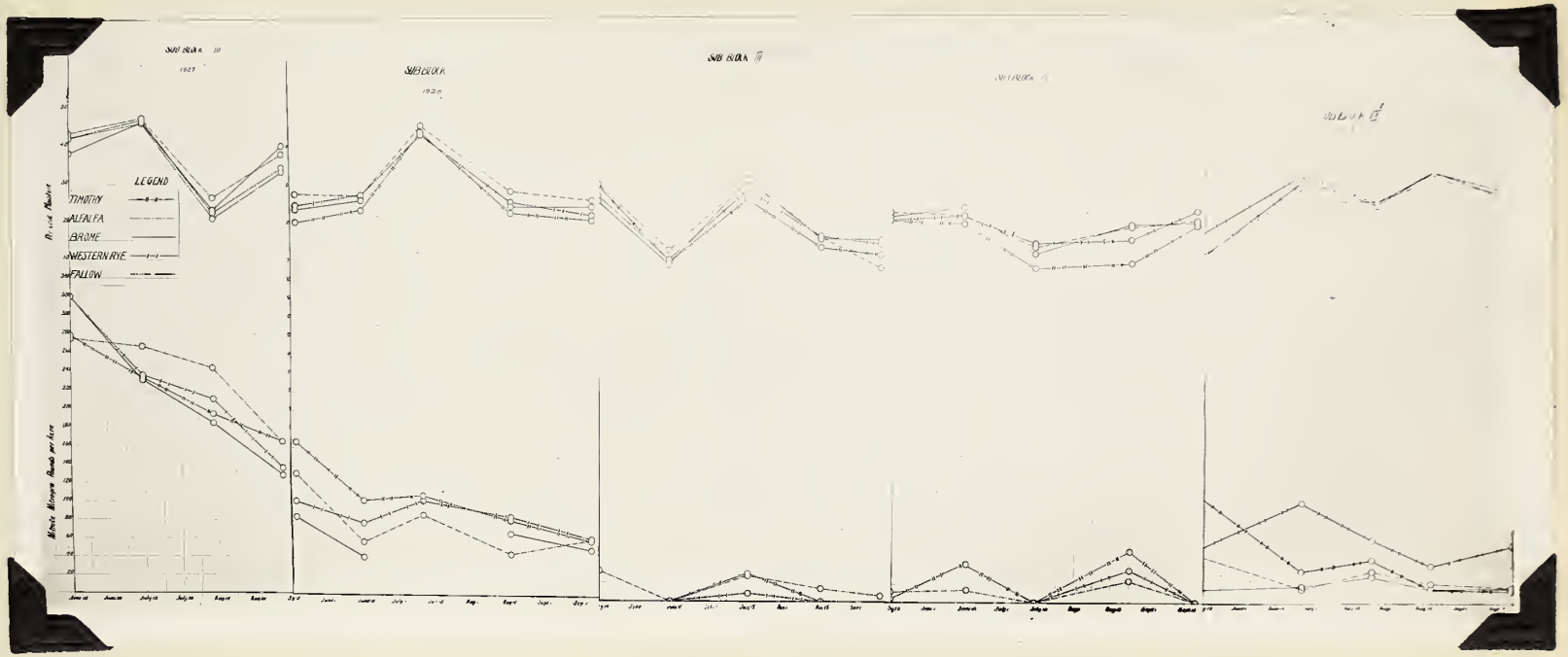
Graphical representation of the concentration of nitrates and moisture in sub-block II (1927-1931).



Nitrate nitrogen expressed as lbs. per acre in upper 40 inches of soil. The figures for moisture content represent only the upper six inches of soil. Note that the sub-block was plowed up in the middle of July, 1930. For season 1931 graph shows nitrates produced under wheat.

Graph III

Graphical representation of the concentration of nitrates and moisture in sub-block III (1927-1931).



Nitrate nitrogen expressed as lbs. per acre in upper 40 inches of soil. The figures for moisture content represent only the upper 6 inches of soil.

Water Soluble Phosphorus

There has been much controversy on the subject of determination of available phosphorus, that is, of phosphorus present in the soil that could be readily utilized by the plants. Several methods have been evolved by Neubauer, Lemmermann, Winogradsky, Truog and others (28,41,60,65). Neubauer makes use of living plants for the determination. Winogradsky evolved the Azotobacter method. Other investigators employ the methods of extraction of soil with different types of solvents which are supposed to simulate the action of roots. Much can be said for these methods, but one must always bear in mind that little as yet is known about the actual form of phosphorus absorbed, and as to how plants extract it from the soil. Any method employed is therefore merely empirical.

In this work it was decided to use distilled water for making soil extracts, because it was thought that, whatever the effect of the plants on the soil or its solution, the phosphorus that was present in a water extract would be the most readily available to the plants.

The method used consisted of shaking up 20 grams of soil with 100 cc. of water (1:5 extract). 50 cc. of the clear solution obtained by filtering the water extract with a Buchner funnel was then evaporated to dryness and ignited. The residue was taken up with dilute HCl and the phosphorus thus brought into solution was determined by Parker's method.

The ignition of the substances obtained by extraction of the soil was carried out to remove the organic matter which would otherwise interfere with the blue color developed in the determination, giving it a yellow tinge. On ignition, however, the organic phosphorus present was changed to the phosphate form and determined as such. A criticism of this procedure is that the plants may not be able to utilize organic phosphorus and thus the figures may be of little value. However, Whiting (67) with his work on phytin, has shown that plants, directly or indirectly, can make very good use of organic phosphorus.

The data obtained during the season 1931 is given in Table VII. In considering the results of one season's work one notices that the greatest amount of water soluble phosphorus is present in the upper six inches of soil, with a gradual decrease downwards. In fact in the subsoil there is very little water soluble phosphorus present. It was possible to test the water extracts of a few subsoils directly without first evaporating them down and igniting the organic matter. No phosphates were detected in such solutions before ignition, showing that all the water soluble phosphorus in the subsoil was present in the organic form.

There is no great difference between the figures of the individual plots. However, the concentration of phosphates in the top layer of the soil seems to be slightly

higher under grasses and, in particular, under alfalfa than under wheat, as shown in "vertical average" column of Table VII. Furthermore during the actual determination, difference in the intensity of the blue colour developed was clearly seen. Since, however, the differences are only very slight and are almost within the range of experimental error, one must avoid any very definite conclusion on this point.

There does not seem to be any definite fluctuation in water soluble phosphorus during the growing season, but the figures show a decrease in the month of September. Only further work during a number of summers can show whether this finding is a regular phenomenon or is merely peculiar to this past season.

Table VII. Water soluble phosphorus as PO_4 (1931)
Parts per million of dry soil.

Sample	Sub-block	Crop	May 13	June 25	July 24	Aug.18	Sept.15,25	Horizontal averages	Vertical averages
A	I	Wheat# after timothy	8.1	8.3	9.6	8.9	5.4	8.1	
B	"	" " "	3.5	3.7	3.2	4.1	2.8	3.5	
C	"	" " "	.6	.3	.2	.3	.5	.4	4.0
A	I	" " alfalfa	9.3	10.2	10.5	9.9	6.7	9.3	
B	"	" " "	4.3	3.7	3.1	3.5	2.5	5.4	
C	"	" " "	.8	.6	----	.2	.6	.5	4.4
A	I	" " brome	9.6	8.1	8.7	10.3	5.3	8.4	
B	"	" " "	3.6	4.3	3.8	4.1	2.6	3.7	
C	"	" " "	1.8	.7	.2	.2	.8	.7	4.3
A	I	" " W. rye	9.3	9.9	8.7	10.6	7.8	9.2	
B	"	" " "	4.1	3.7	3.6	4.8	3.0	3.8	
C	"	" " "	.7	.4	.3	.1	.5	.4	4.5
A	II	Wheat## after alfalfa	6.6	9.7	10.6	12.1	5.7	8.9	
B	"	" " "	3.9	4.5	2.4	----	3.5	3.6	
C	"	" " "	.6	.4	.3	.2	.9	.5	4.3
A	II	" " brome	10.2	9.2	10.9	11.9	7.7	10.0	
B	"	" " "	3.7	4.6	4.5	4.6	3.3	4.1	
C	"	" " "	1.2	.5	.4	.2	1.0	.7	4.9

Table VII. (Continued)

Sample	Sub-block	Crop	May 13	June 25	July 24	Aug.18	Sept.15,25	Horizontal averages	Vertical averages
A	II	Wheat## after timothy	8.3	10.1	10.6	9.1	5.8	8.8	
B	"	" " "	4.5	5.2	4.0	6.2	4.1	4.8	
C	"	" " "	.5	.2	.5	.7	.0	.4	4.7
A	II	" " W. rye	7.6	9.7	9.5	9.5	5.3	8.3	
B	"	" " "	3.7	3.2	3.7	4.3	2.6	3.5	
C	"	" " "	.6	.4	.6	.2	1.1	.6	4.1
A	III	Timothy	9.0	11.8	11.9	12.2	8.1	10.6	
B	"	"	3.9	4.4	4.7	3.9	2.8	3.9	
C	"	"	.8	.5	.9	.1	.5	.6	5.0
A	III	Alfalfa	10.0	14.3	12.4	13.5	9.5	11.9	
B	"	"	4.1	3.9	4.4	6.0	3.5	4.4	
C	"	"	.9	.4	.8	.7	.6	.7	5.7
A	III	Brome	10.9	11.9	12.2	13.5	8.2	11.3	
B	"	"	4.9	4.0	3.7	3.9	3.5	4.0	
C	"	"	1.0	.7	.8	.6	1.3	.9	5.4
A	III	W. rye	7.9	12.0	11.2	12.8	8.9	10.6	
B	"	"	5.9	4.1	3.4	3.1	3.5	4.0	
C	"	"	1.7	.5	.6	.6	.5	.8	5.1
A		Fallow	10.4	11.7	11.2	12.6	10.6	11.3	
B		"	3.5	2.5	3.2	3.0	1.9	2.8	
C		"	.6	.3	.0	.0	1.0	.4	4.8

Third crop of wheat after breaking.
First " " " " "

Total Nitrogen

Total nitrogen determinations have been carried out on all soil samples taken in May during the seasons 1927 to 1931. However, for the sake of brevity it was decided not to include the table of the results in this report. The figures showed irregular fluctuations which were much greater than the experimental error allowed in the determination, but it may be stated that no great change in nitrogen content of the soil was noticed. It must be borne in mind, however, that a five year period is too short to show any appreciable change in nitrogen content.

Work by F. T. Shutt (49) on soil samples from Indian Head, Saskatchewan, has shown that loss in nitrogen from the soil due to agricultural practices and the growing of crops does take place in prairie province soils. He, however, compared the nitrogen content of a soil which had been under cultivation twenty two years with that of the virgin prairie soil near by.

Microorganisms

Bacterial counts and fungal counts were made during the seasons of 1929, 1930 and 1931.

During the summer of 1929 counts on soil under the following crops were made:

Fallow	
First crop of wheat after timothy	Sub-block I
" " " " " western rye	Sub-block I
" " " " " alfalfa	Sub-block I
Alfalfa	Sub-block III
Timothy	Sub-block III
Western rye	Sub-block III

Work on the same plots of sub-blocks I and III was carried out in 1930, and in addition counts for plots of sub-block II were made from the time it was plowed up in June.

In 1931 investigations were carried out on the following plots:

Fallow	
First crop of wheat after alfalfa	Sub-block II
" " " " " brome	Sub-block II
" " " " " timothy	Sub-block II
" " " " " western rye	Sub-block II
Timothy	Sub-block III
Alfalfa	Sub-block III
Brome	Sub-block III
Western rye	Sub-block III

The results of these investigations are recorded in Table VIII and Graphs IV to VI. The data in Table VIII have been obtained from the composite samples of soil consisting

of composite samples taken from four similar plots from each sub-block.

In examining the findings for sub-block III in the three years from 1929 to 1931, several points of interest are brought to light. During this period the fungal counts under alfalfa were consistently higher than under timothy and western rye grass. The counts of these latter plots do not show any significant difference. In 1931 counts were made on brome plots for the first time and throughout the season were consistently low. During the season of 1931 it was noticed that the fungi prevalent under the grasses, as well as under alfalfa were of the genus Penicillium (27).

In the case of bacterial numbers the alfalfa plots again were in the lead, but there were no significant differences in numbers of bacteria under the western rye, timothy and brome plots.

When one compares, in Graphs VI and IV, the grass and alfalfa plots (Graph VI) with the plots carrying wheat after the sod has been broken up (Graph IV), one finds that during the seasons 1929 and 1930 the counts of fungi were lower under wheat than under grasses or alfalfa. In 1931, however, the fungal counts in the case of sub-block II plots carrying the first crop of wheat after the perennial grasses (Graph V) were higher than in the case of any plots in sub-block III, excepting those supporting alfalfa. The alfalfa plots plowed up in 1930 gave low counts during the 1931 season.

This was probably due to the fact that the proteolitic fungus Mucor develcped on the plate very rapidly (4,35,36). In fact these plates had to be counted after two days incubation (see Figure III) instead of the usual time, because if this was not done they became so overgrown by the fungus that the separate colonies could not be distinguished (compare Figures III and IV). It will be remembered that the medium used was a peptone agar medium which would encourage the development of a proteolitic fungus (20). Probably other types of fungi were present in the soil, but due to the rapid growth of Mucor on the plates, no opportunity was given them for development. This opinion is confirmed by the fact that during the later part of the season, when the Mucor colonies did not spread with great rapidity on the plates, Penicillium colonies appeared on the third day of incubation as illustrated in Figure IV. The great numbers of Mucor present in the soil after an alfalfa crop has been plowed under is easily explained. Mucor is a fast growing proteolitic fungus, and alfalfa residues are rich in protein. When incorporated with the soil, alfalfa forms a suitable medium for the fungus in question.

Great numbers of the Penicillium type of fungus developed in the soil of the broken up brome sod as seen in Figure V. These may have been stimulated by the incorporation of large amounts of carbonaceous organic material.

In considering Table IX supplied by the Field Crops Department one notices that more carbohydrates have been plowed under in the case of brome than in the case of western rye

grass and timothy. At the same time the protein carbohydrate ratio of bromo residues is wider than that of the other two grasses. From this we can surmise that more of the nitrates of the soil will be used up by the organisms engaged in the decomposition of the brome residues (13,14,43,50,62). The numbers of fungi after timothy were lower than after western rye grass, as seen in Table VIII and in Figure V, but as this finding is not confirmed by the previous two year's work on sub-block I, no further comment can be made.

The bacterial numbers of grass and wheat plots did not show any significant differences in 1930 and 1931. In 1929, however, as seen from Graphs IV and VI bacterial counts were lower under the grass and alfalfa sods than under the wheat. There is nothing worthy of mention in connection with bacterial numbers under the wheat plots following the different sods, except that those after alfalfa were consistently slightly higher, but these differences were so small that they are practically within the range of experimental error.

Nothing definite can be stated about the microorganisms under the fallow plots. The Graph IV shows that in 1929 and 1930 the fungal counts under the fallow were high, ranging around the 50-60 thousand mark, whereas the counts under wheat were about half that amount. In 1931, however, numbers of fungi under the fallow are relatively low. This is clearly seen in Graph V.

As regards the bacterial numbers under the fallow we notice from Graph IV that the numbers were low in 1929, but

comparatively high in 1930. In 1931 they were again low as seen from Graph V.

Starkey# and other investigators have done a considerable amount of work on the number of microorganisms in soil adjacent to the roots of living plants, and they have shown that as a rule the bacteria and fungi are more numerous in the vicinity of plants than at a distance from them. These findings would suggest that greater numbers of organisms might be found under growing crops than in fallow land. The higher moisture content of the fallow land, however, would tend to counteract this effect.

One point which should be mentioned in connection with this investigation is that the fallow plots from year to year were on different fields and following different crops. The inconsistency in these results may be therefore attributed to this lack of uniformity in conditions.

One general finding that seems to be consistent during the three years of investigation is that there is a close relationship between the seasonal fluctuations in numbers of bacteria and fungi in all plots throughout the season (Graph IV-VI).

In bringing the discussion on the numbers of micro-organisms to a conclusion one may say that the figures obtained

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(2,4,6,7,16,17,22,23,24,26,33,38,40,43,48,52,53,54,58,59).

for fungi seem to be of greater significance than those for bacteria, for the fluctuations in numbers, as influenced by different crops and crop residues, are much greater and more regular in the case of the fungi than in the case of the bacteria.

Of late years Waksman and others have shown that under aerobic conditions fungi form one of the most important groups of organism taking part in the process of decomposition of carbonaceous and other organic material in soil (15,51,62). It is therefore not surprising that their numbers are greatly affected by the incorporation of plant residues with the soil. On the other hand, the bacteria are also of importance in this work, but their numbers are so much larger than those of fungi and there is such a great variety of forms, that it is more than likely that one set of conditions affects the different forms in different ways, and thus very small changes in total numbers occur. In connection with this it must be remembered that the medium used is not one which is suitable for any special form of bacteria.

able VIII. Moisture content and microorganisms in surface soil (1931)

Sub-block	Crop	May 11	May 25	June 11	June 24	July 7	July 21	Aug.11	Aug.26	Sept.10	Sept.22	Ave.
		Moisture in surface soil: per cent.										
II	First crop wheat afr alfalfa	32.1	31.2	28.1	42.5	38.8	17.7	41.1	31.9	31.3	34.0	32.9
"	" " " " ' brome	34.0	31.4	30.3	40.4	37.8	20.2	41.6	32.9	36.2	38.0	34.3
"	" " " " ' timothy	31.9	31.3	30.0	39.3	34.6	19.6	39.2	29.5	32.0	34.5	32.2
"	" " " " ' W. rye	31.8	30.8	29.4	40.5	39.4	20.5	42.7	31.6	35.6	38.0	34.0
III	Timothy	26.5	19.0	21.7	39.7	39.5	21.7	43.3	30.0	32.7	37.0	31.1
"	Alfalfa	29.4	20.9	23.9	40.6	38.6	18.6	42.7	32.5	37.5	30.7	30.5
"	Brome	29.2	21.5	22.9	43.4	36.7	22.8	43.7	32.6	33.1	39.8	32.6
"	W. rye	29.1	24.3	24.4	42.6	36.8	24.5	41.0	32.7	28.8	36.1	32.0
	Fallow	30.2	26.6	26.6	40.9	37.1	29.5	39.8	34.3	35.0	38.4	33.8
	Fallow (Variability		28.6		40.4	39.4	29.2	40.0	31.4	34.3	37.6	
		Bacteria in surface soil: millions per gram										
II	First crop wheat afr alfalfa	36.1	11.6	9.5	14.4	15.9	4.3	19.2	8.8	6.4	5.5	13.2
"	" " " " ' brome	28.4	10.6	7.4	14.3	17.2	4.7	16.1	4.6	5.7	10.3	11.9
"	" " " " ' timothy	26.5	7.8	8.2	11.2	12.5	3.4	10.0	2.3	5.5	8.0	9.5
"	" " " " ' W. rye	24.5	8.1	8.2	12.2	13.5	5.0	12.4	7.7	6.4	10.8	10.9
III	Timothy	12.8	7.0	7.5	11.2	12.8	4.4	17.9	7.9	10.5	9.2	10.1
"	Alfalfa	18.4	6.3	6.9	10.3	15.7	4.7	17.4	8.4	8.6	6.3	10.3
"	Brome	18.7	8.9	7.5	8.5	13.6	4.9	15.1	8.5	8.6	12.7	10.7
"	W. rye	15.6	7.7	6.4	7.5	10.3	4.1	17.0	8.1	6.2	9.0	9.2
"	Fallow	10.2	6.6	3.4	10.9	10.2	4.8	8.9	6.2	4.5	7.6	7.3
"	Fallow (Variability)		8.1		11.8	10.4	4.5	8.8	5.0	5.8	6.8	
		Fungi in surface soil: thousands per gram										
II	First crop wheat afr alfalfa	10.4	22.9	20.7	20.9	25.0	30.6	52.8	44.3	19.8	17.7	26.5
"	" " " " ' brome	86.9	131.7	165.4	281.0	257.0	91.4	237.3	138.8	139.4	96.5	162.5
"	" " " " ' timothy	19.3	20.6	18.1	36.0	32.4	21.4	36.7	32.1	21.4	22.2	26.0
"	" " " " ' W. rye	23.9	27.5	37.8	64.5	60.3	33.6	54.7	70.4	43.5	45.8	46.2
III	Timothy	12.7	16.6	15.1	14.4	22.7	13.5	32.6	28.7	21.0	21.0	19.2
"	Alfalfa	47.0	27.4	33.5	48.8	74.5	34.5	65.4	64.3	52.4	35.8	48.4
"	Brome	13.6	12.0	6.6	8.6	18.5	11.0	29.0	15.6	14.1	16.2	14.5
"	W. rye	15.0	12.3	10.4	18.7	18.7	15.8	25.4	39.0	21.3	24.5	20.1
	Fallow	15.6	15.2	8.9	30.1	27.4	19.3	31.9	38.5	23.0	25.2	23.5
	Fallow (Variability)		22.2		35.7	30.6	16.3	31.5	35.3	25.0	27.0	

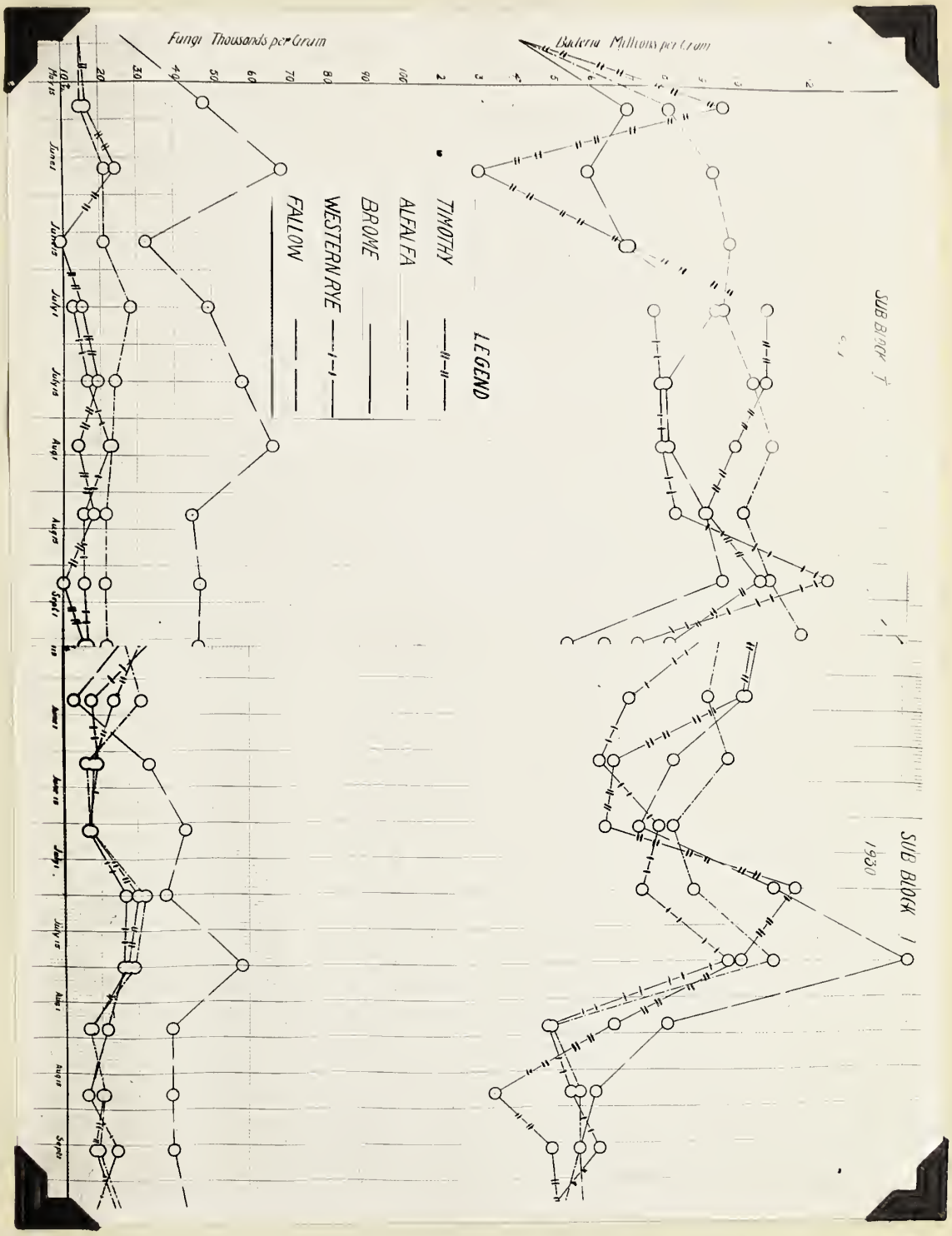
Table IX. Crop residues in upper 6 inches, per acre - Plowed under. (Organic matter basis)

Crop	Organic Matter			Protein			Crude Fibre			Carbohydrates			#Ratio of protein to carbohydrates
	Roots	Stubble	Total	Roots	Stubble	Total	Roots	Stubble	Total	Roots	Stubble	Total	
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
Alfalfa	7304	657	7961	993	73	1066	2052	306	2358	6232	579	6811	1:6.3
Brome	6564	408	6972	499	16	515	2050	152	2202	6053	390	6443	1:12.5
Timothy	5695	811	6506	589	47	636	1754	229	1983	5074	755	5829	1:9.2
W. Rye	3179	1263	4442	352	81	433	1065	484	1549	2811	1174	3985	1:9.2

Carbohydrates include crude fibre + N - free extract.

Graph IV

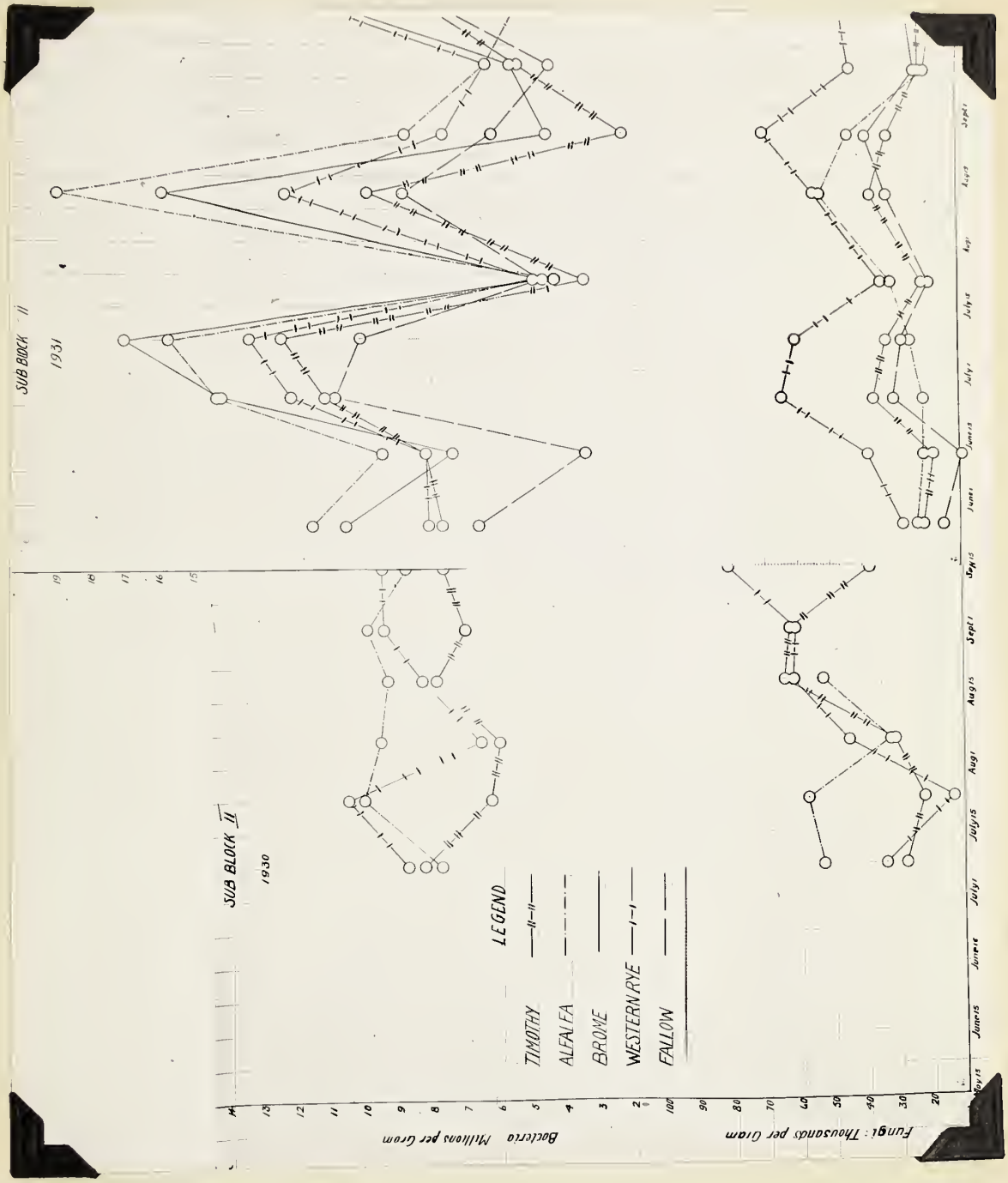
Graphical representation of bacterial and fungal counts of sub-block I (1929 and 1930).



These counts of microorganisms are from plots under wheat following the perennial crops mentioned in the legend. Note high counts of fungi under fallow.

Graph V

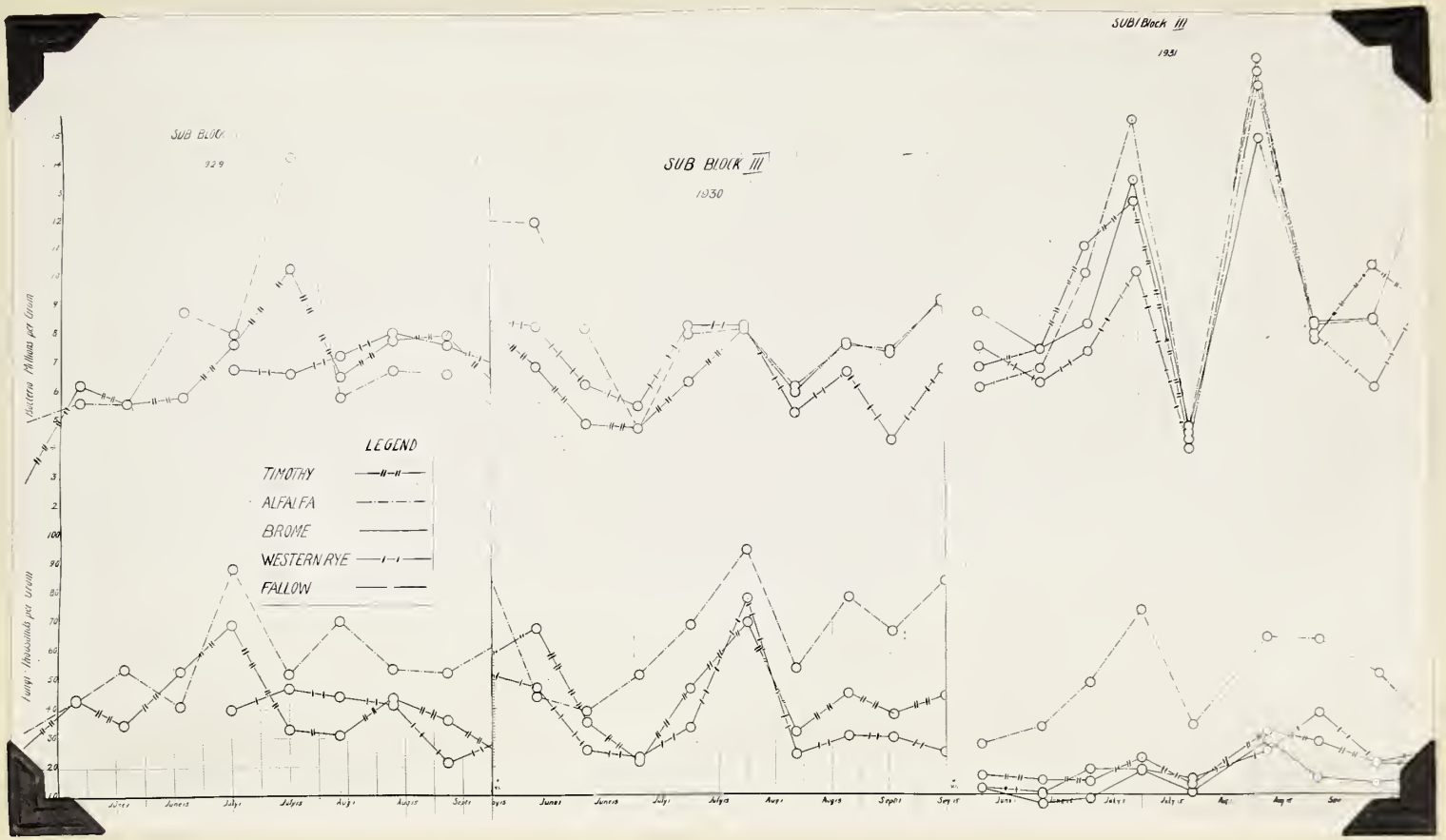
Graphical representation of bacterial and fungal counts of sub-block II 91930 and 1931).



Sub-block II was plowed up in July 1930. The graph shows the numbers of microorganisms under wheat after the perennial crops. The figures for fungi under brome were not included because of their magnetude. Note low count of fungi under fallow, (compare with graph IV) and the small differences in bacterial numbers of the different plots.

Graph VI

Graphical representation of bacterial and fungal counts of sub-block III (1927-1931)



Note the higher count of bacteria and especially of fungi under alfalfa than under the grasses, the low count of fungi under brome, and the correlation between the fungal and bacteria numbers.

FUNGI PLATES

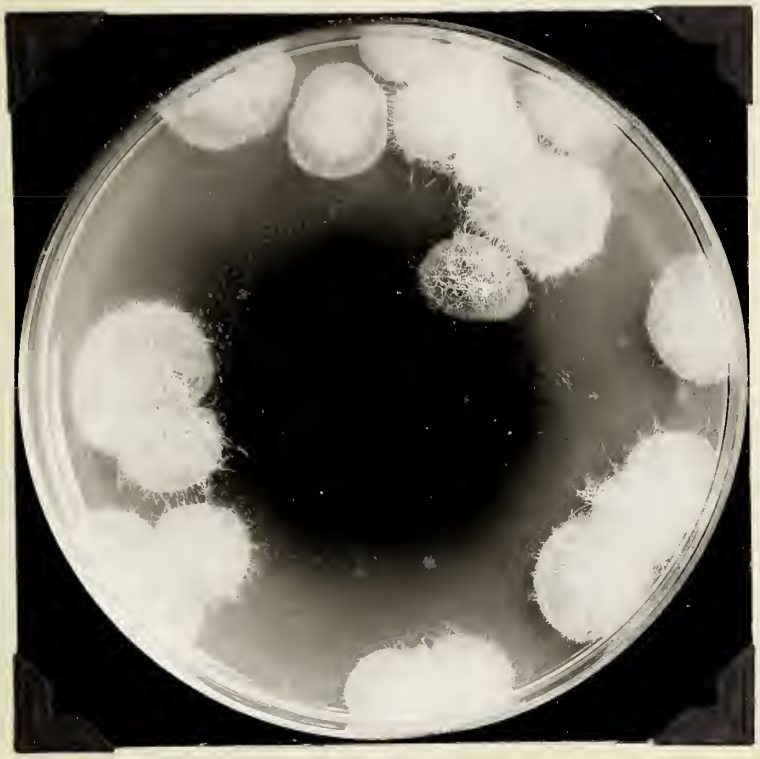


Figure III

Plated from soil containing alfalfa residues. Note rapid development of Mucor after two days incubation. No other fungi are seen.

Figure IV

Plated from soil containing alfalfa residues. Note the growth of Mucor and the development of Penicillium colonies after three days incubation.

FUNGI PLATES (After three days incubation)

Figure V

Plated from soil containing Brome residues. Note great numbers of Penicillium colonies.

Figure VI

Plated from soil containing timothy residues. Note small numbers of Penicillium colonies as compared with Figure V.

FUNGI PLATES (After three days incubation)

Figure VII

Plated from soil containing western rye residues.

Figure VIII

Plated from fallow soil.

FUNGI PLATES (After three days incubation)

Figure IX

Plated from soil under growing alfalfa. Note the numerous Penicillium colonies as compared with Figures X, XI, XII.

Figure X

Plated from soil under growing brome. Note small numbers of colonies. Compare with Figure IX.

FUNGI PLATES (After three days incubation)

Figure XI

Plated from soil under growing timothy. Note the small numbers of colonies. Compare with Figure IX.

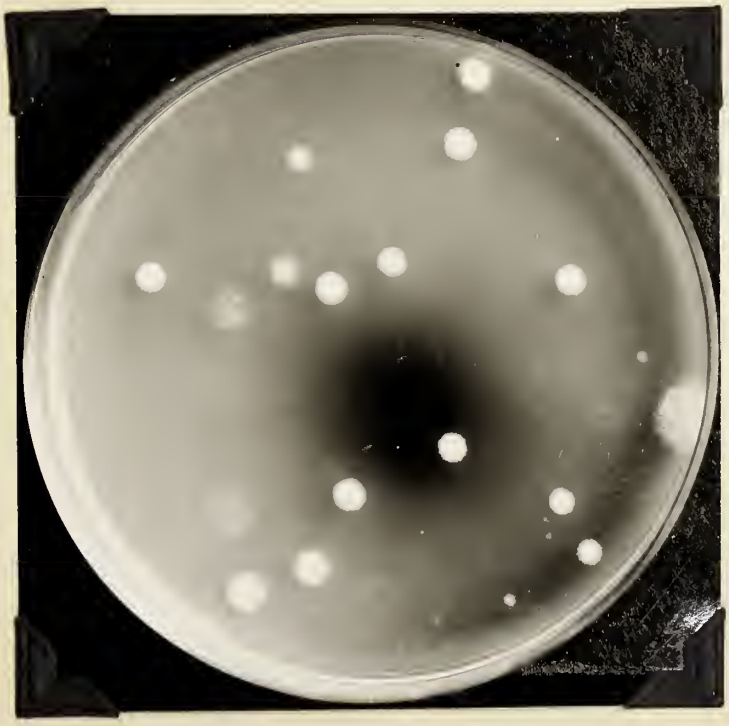


Figure XII

Plated from soil under growing western rye. Note small numbers of colonies. Compare with Figure IX.

SUMMARY

The following determinations: nitrate, moisture, water soluble phosphorus, nitrogen, were made on samples of soil taken at monthly intervals from plots under alfalfa, timothy, brome grass, western rye grass and wheat and fallow, throughout the growing season of 1931. Surface, subsurface and subsoil samples to a depth of 40 inches were obtained from the plots of each of the three sub-blocks. In addition, bacterial and fungal counts on samples of the surface 6 2/3 inches from the plots of sub-blocks II and III were made twice a month.

Nitrate determinations were carried out by the phenol disulfonic acid method. For water soluble phosphorus the Deniges method as modified by Parker was used. For total nitrogen the Gunning's method was employed. The fungal and bacterial numbers were obtained by means of the plate count method. From the experiments conducted in 1931 and previous years the following results were obtained:

(1) Fallow land contained more nitrate nitrogen than cropped land in the latter part of the season.

(2) Soils cropped to cereals were higher in nitrate content than alfalfa and perennial grass land.

(3) Soil under alfalfa was nearly as low in nitrates as the soil supporting grasses.

(4) When alfalfa plots were plowed up nitrification proceeded more rapidly than in the case of the plowed up grass plots.

(5) As compared to timothy and western rye grass the growing brome crop and its residues seem to depress the nitrate accumulation.

(6) The timothy and western rye grass crops,and more particularly their residues,did not seem to have either a depressing or stimulating effect on nitrate production as compared with brome and alfalfa.

(7) The moisture content of the fallow was higher than that of any other plots.

(8) No close correlation was noticed between the fluctuations of nitrate and moisture content.

(9) No significant differences were noticed in the moisture content of the soil under the different crops.

(10) No great differences in water soluble phosphorus in the soil under the different crops could be detected, but there were indications that the concentration under the forage crops, and especially under alfalfa, was higher than under cereals.

(11) The results for nitrogen determination showed relatively large irregular fluctuations, and therefore it is difficult to make any definite statement in connection with this part of the investigation. However, the figures seem to indicate that there was no significant decrease

in nitrogen content of the soil after five years cropping.

(12) Relatively large numbers of Genus Mucor fungi developed in the soil after the plowing up of alfalfa.

(13) Relatively large numbers of Genus Penicillium fungi were obtained after the breaking up of brome sod.

(14) Greater numbers of fungi were observed under the alfalfa than under the brome, timothy and western rye grass sods.

(15) The numbers of bacteria in the soil under the various crops and fallow showed differences which cannot be considered to be significant.

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